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A multi-polarization study of Arctic sea ice in C-band and X-band

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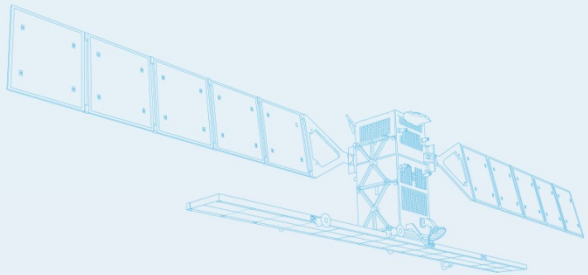
Outline

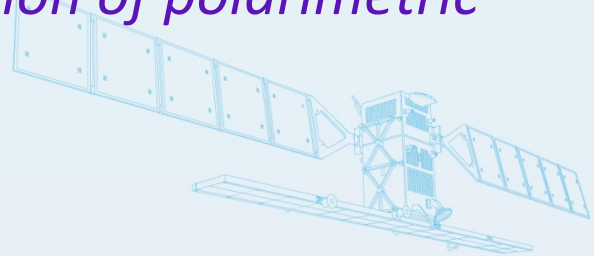
- Objectives
- Some preliminaries
- Show study areas and data
- SAR image segmentation
- Examples of polarimetric analysis
- Summary



Research goal

Our objective is

- *Combine in-situ and satellite observations to develop methodologies for analysis of polarimetric SAR data of sea ice*
- *to improve physical understanding of the interaction EM waves and sea ice, and the interpretation of polarimetric sea ice features*



SAR polarimetry

Scattering matrix:

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \frac{\exp(jkr)}{r} \begin{bmatrix} s_{hh} & s_{hv} \\ s_{vh} & s_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}$$

Pauli target vector: $\mathbf{k}_P = \frac{1}{\sqrt{2}}[s_{hh} + s_{vv}, s_{hh} - s_{vv}, s_{hv} + s_{vh}, j\,(s_{hv} + s_{vh})]$

Coherence matrix: $T = < \mathbf{k}_P \mathbf{k}_P^\dagger >$

In-coherent taget decomposition: $T = \sum_{i=1}^{N} \gamma_i T_i$

Analysis of SAR scenes

Single polarization

$$s_l = \mathrm{Re}\{s_l\} + j\,\mathrm{Im}\{s_l\}$$

$$I_l = |s_l|^2$$

$$I_L = \frac{1}{L}\sum_{i=1}^{L} s_i$$

→ Image type processing
1-D statistics

Multiple polarizations

$$\mathbf{s} = [s_{hh}, s_{hv}, s_{vh}, s_{vv}]^t$$

$$C = \frac{1}{L}\sum_{i=1}^{L} \mathbf{s}_i \mathbf{s}_i^*$$

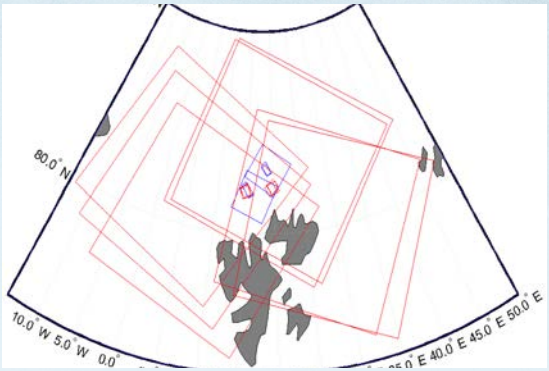
→ Polarimetric analysis

→ Statistical analysis

Quad-pol vs. dual & single pol.

Advantages:

- Large information contents
- Carries scattering information

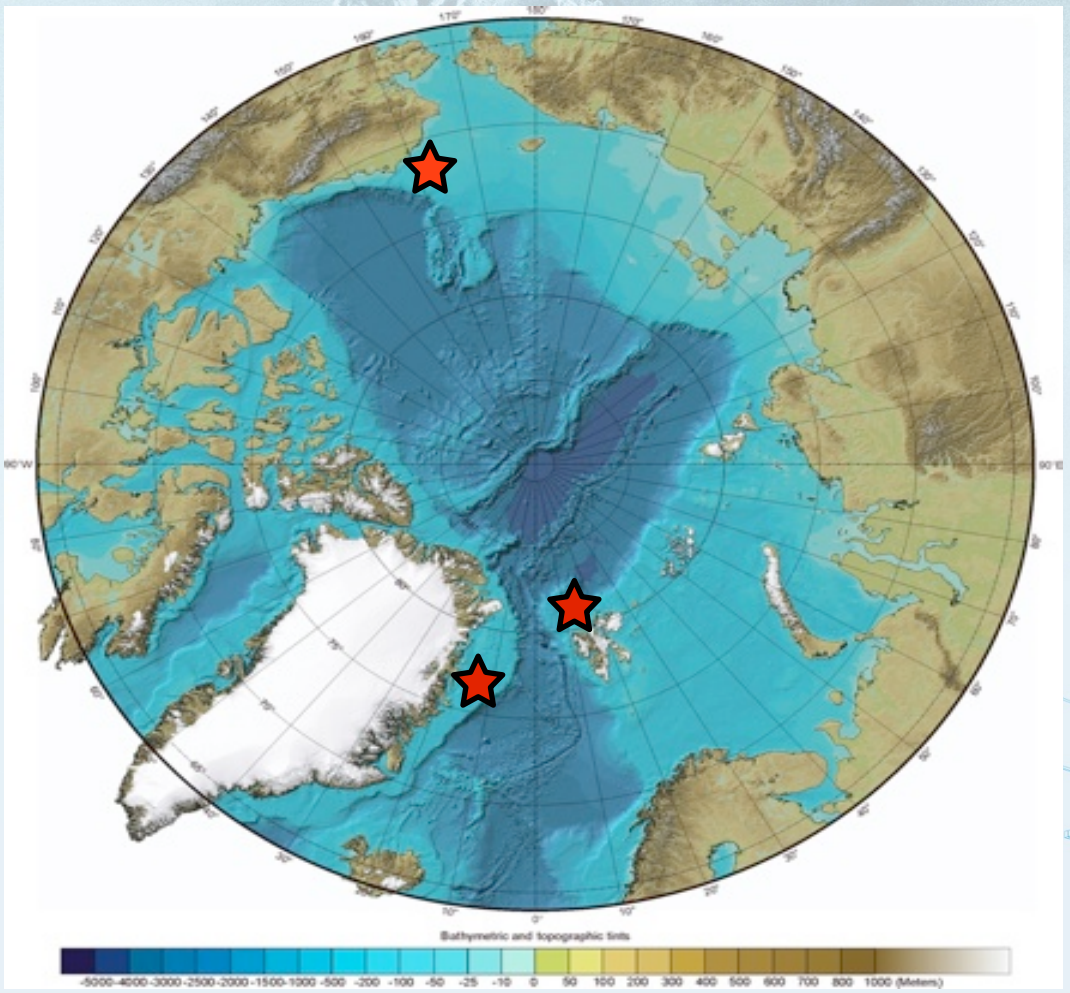


Disadvantage:

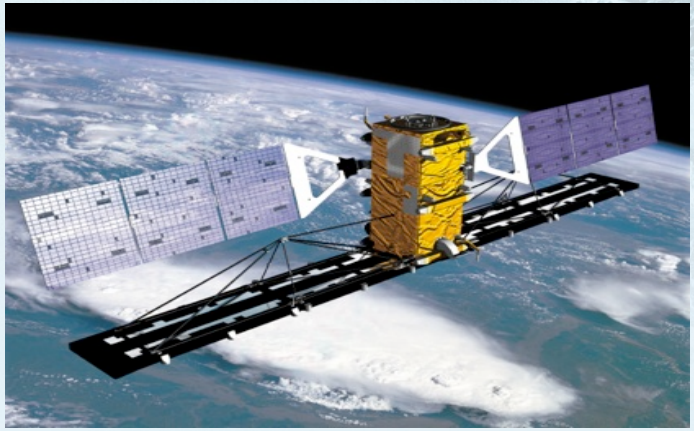
- Small scenes
- Large data volume/unit area

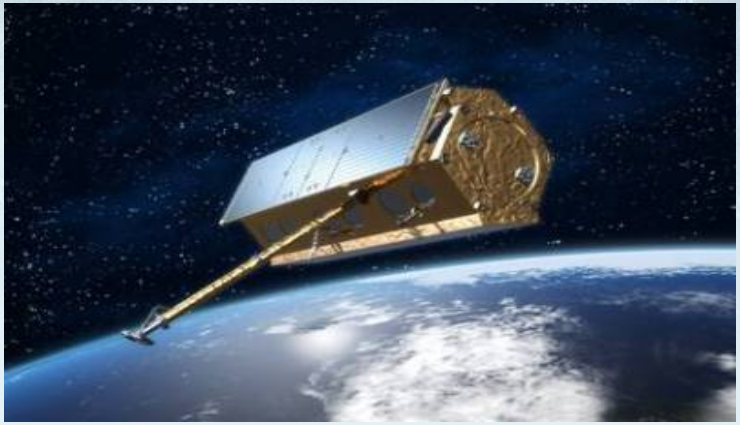
Climate related products and/or operational products will rely on dual or single polarization SAR data

Areas of interest



Satellite data:





Radarsat 2

C-band
Frequency: 5.4 GHz (5.5 cm)
Quad-pol & dual
Scene size (standard): 25 x 25 km
Resolution: az 7.6 m, ra 9 m

TerraSAR-X

X-band
Frequency: 9.65 GHz (3.1 cm)
Single & Dual-pol (HH-VV, HH-HV, VV-VX)
Scence size (StripMap): 15 x 50 km
Resolution: az 6.6 m, gra 1.7-3.4 m

Validation measurements

- Ground Electromagnetics (Geonics EM31) and snow depth measurements
- Airborne EM profiling (AWI-EM Bird)
- Calibration and Validation Drillings
- UAV measurements

Helicopter EM

Drillings

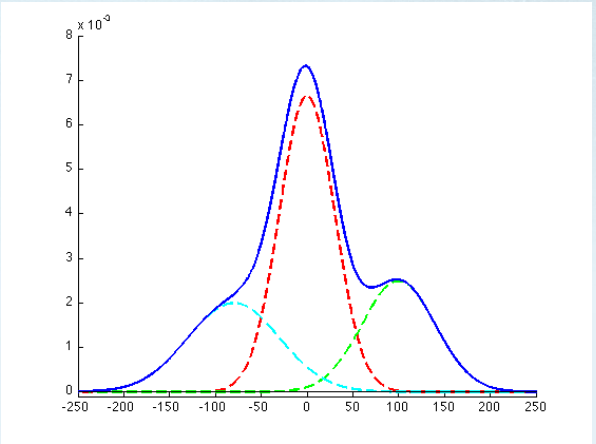
UAV measurements

Statistical modelling

The global pdf of a SAR image is modelled as a mixture of non-Gaussian pdfs:

- good representation of the data
- flexible to accommodate large variations in the data

$$p(\mathbf{x};\mathbf{q}) = \sum_{i=1}^{K} \mu_i p_i(\mathbf{x};\mathbf{q}_i)$$



This model is cast into a clustering algorithm which:

- tries to recover mixture components using the EM algorithm
- assigns pixels to clusters according to a Bayesian rule
- includes spatial context using a Markov Random Field model

Features

Given a local neighbourhood of SLC vectors, calculate the covariance matrix

$$\mathbf{s}_i = \begin{bmatrix} S_{hh} \\ S_{hv} \\ S_{vh} \\ S_{vv} \end{bmatrix} \quad \Longrightarrow \quad \mathbf{C} = \begin{bmatrix} <|S_{hh}|^2> & <S_{hh}S_{hv}^*> & <S_{hh}S_{vh}^*> & <S_{hh}S_{vv}^*> \\ <S_{hv}S_{hh}^*> & <|S_{hv}|^2> & <S_{hv}S_{vh}^*> & <S_{hv}S_{vv}^*> \\ <S_{vh}S_{hh}^*> & <S_{vh}S_{hv}^*> & <|S_{vh}|^2> & <S_{vh}S_{vv}^*> \\ <S_{vv}S_{hh}^*> & <S_{vv}S_{hv}^*> & <S_{vv}S_{vh}^*> & <|S_{vv}|^2> \end{bmatrix}$$

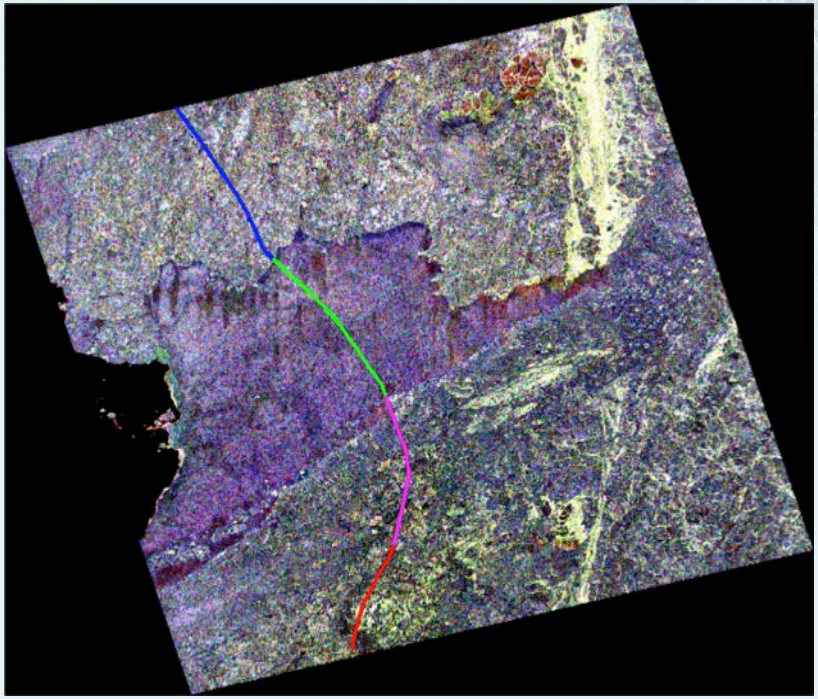
Six Real Features:

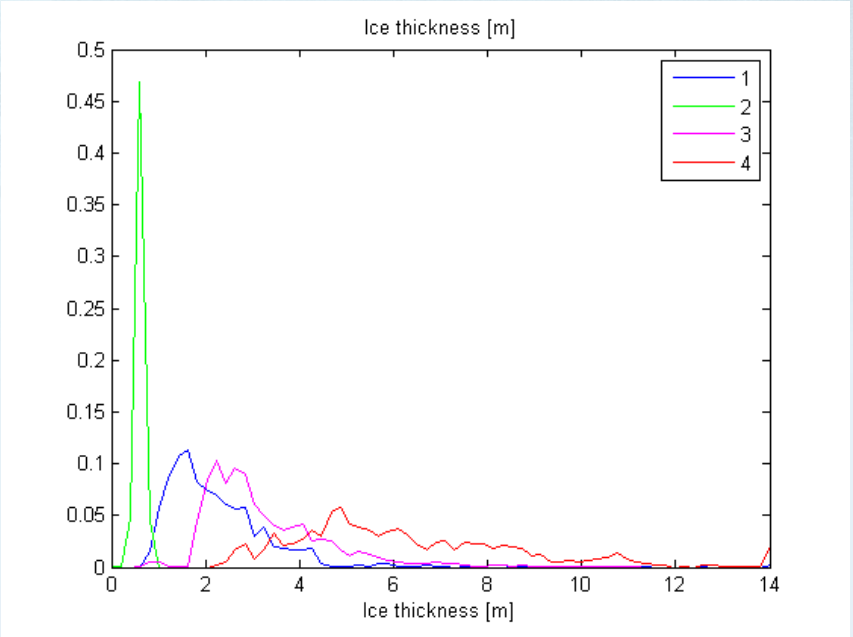
1. A non-Gaussianity measure: relative kurtosis RK= $\frac{1}{Nd(d+1)} \sum_{i=1}^{N} [\mathbf{s}_i^H \mathbf{C}^{-1} \mathbf{s}_i]^2$
2. An absolute backscatter value: geometric Brightness $B = \sqrt[d]{\det(\mathbf{C})}$
3. A cross-polarisation fraction or ratio: $\mathbf{C}_{hv}/B$
4. A co-polarisation ratio: $\mathbf{C}_{vv}/\mathbf{C}_{hh}$
5. The co-polarisation correlation magnitude: $|\rho| = |\mathbf{C}_{hhvv}| / \sqrt{(|\mathbf{C}_{hhhh}|\ |\mathbf{C}_{vvvv}|)}$
6. The co-polarisation correlation angle: $\angle\rho = < \phi_{hh} - \phi_{vv} >$

Note: All features are model independent.

Ice thickness- Fram Strait

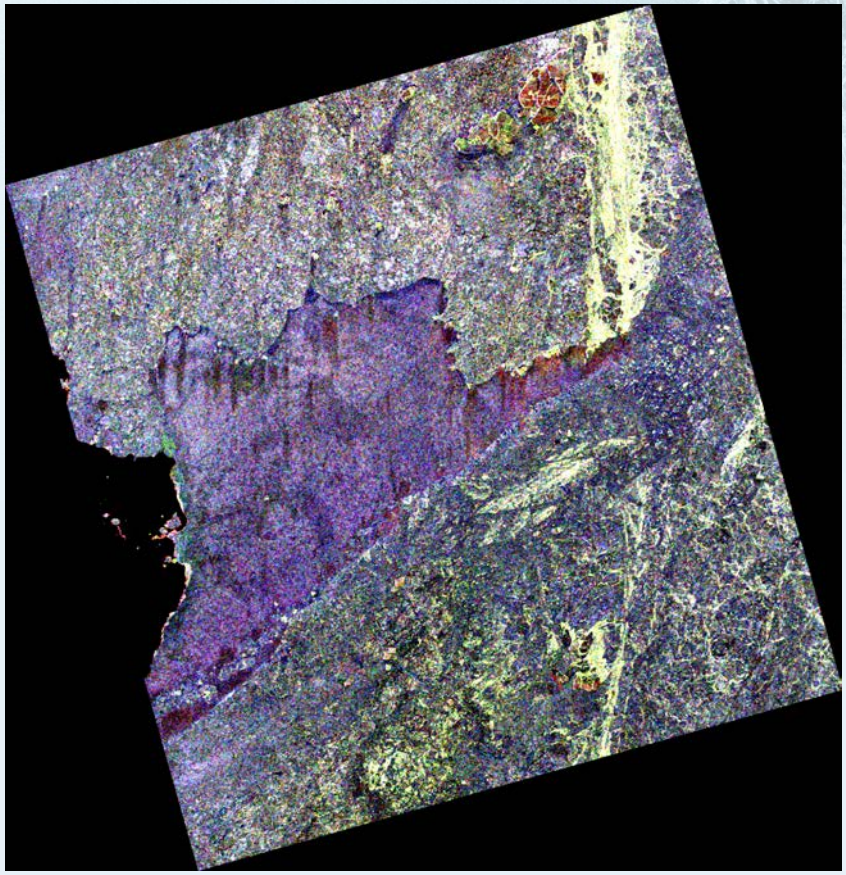
RS2 image: Fast ice Fram Strait of Svalbard, September 2011

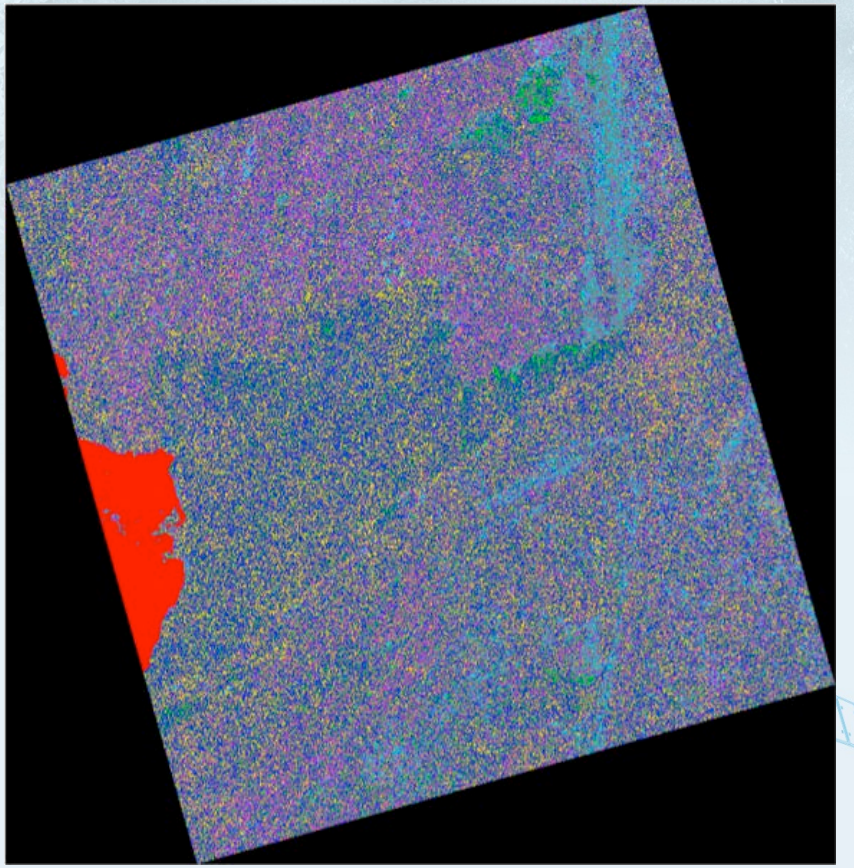




Segmentation (6x6, 7 classes)

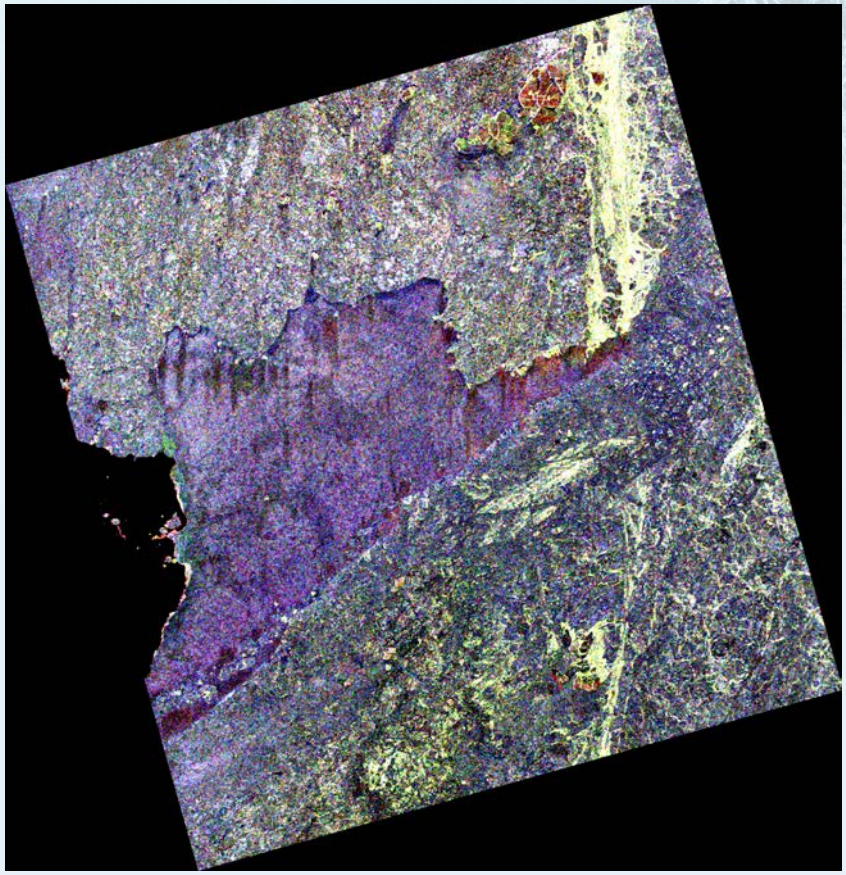
(RS2 image: Fast ice in the Fram Strait, September 2011)

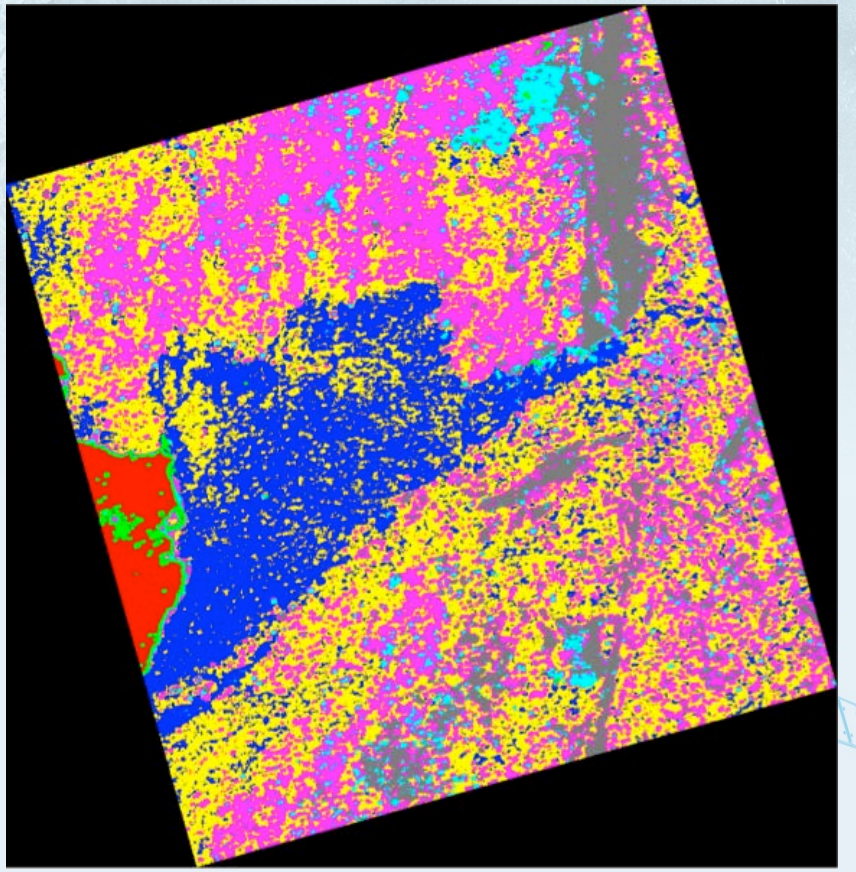




Segmentation (31x31, 7 classes)

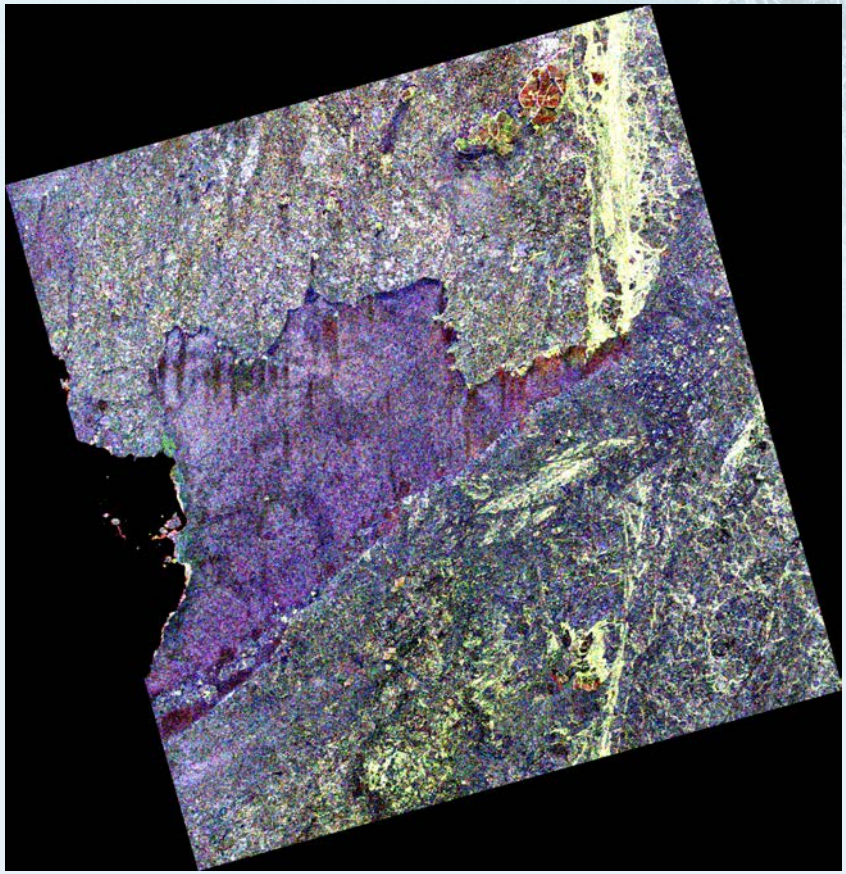
(RS2 image: Fast ice in the Fram Strait, September 2011)

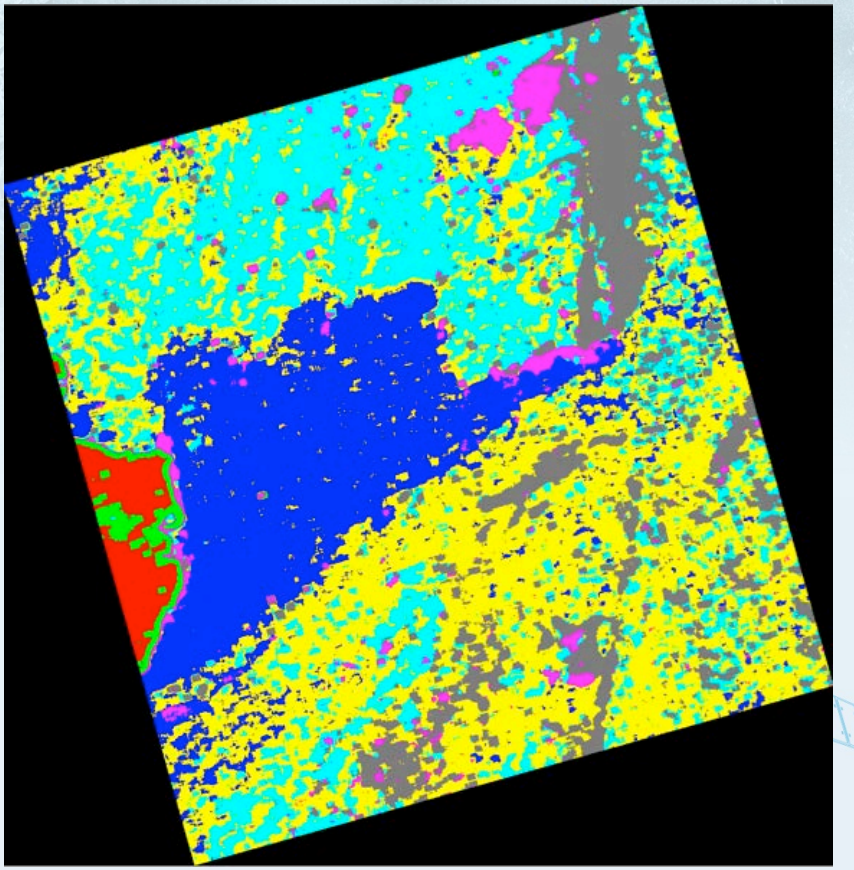




Segmentation (51x51, 7 classes)

(RS2 image: Fast ice in the Fram Strait, September 2011)





Shannon Entropy

Definition: $H(\mathbf{S}) = -\int \log[p_{\mathbf{S}}(\mathbf{s})]\, p_{\mathbf{S}}(\mathbf{s}) d\mathbf{s}$

Gaussian pdf: $p_{\mathbf{S}}(\mathbf{s}) = \frac{1}{\pi^d |\mathbf{\Gamma}_s|} \exp(-\mathbf{s}^\dagger \mathbf{\Gamma}_s^{-1} \mathbf{s})$

Gaussian Shannon Entropy: $H_d^G(\mathbf{S}) = d\, \log[\pi I_0] + \log[\delta] + d, \quad \text{where } \delta = |\mathbf{\Gamma}_s)|/\text{tr}(\mathbf{\Gamma}_s)$

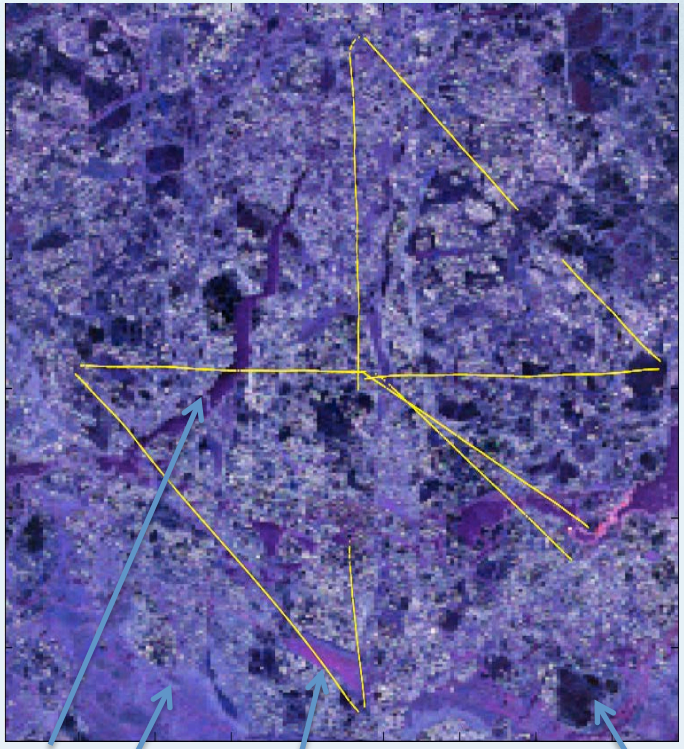
Product model: $S = \sqrt{T}\boldsymbol{X}$

Non-Gaussian Entropy: $H_d^{nG}(\mathbf{S}) = H_d^G(\mathbf{S}) - \{\log[\pi^d e^d] + \int_0^\infty \log[c_d h(u)] g(u) du\}$

Ice thickness – drift ice

RS2 image: Drift ice North of Svalbard, April 2011

Helicopter track

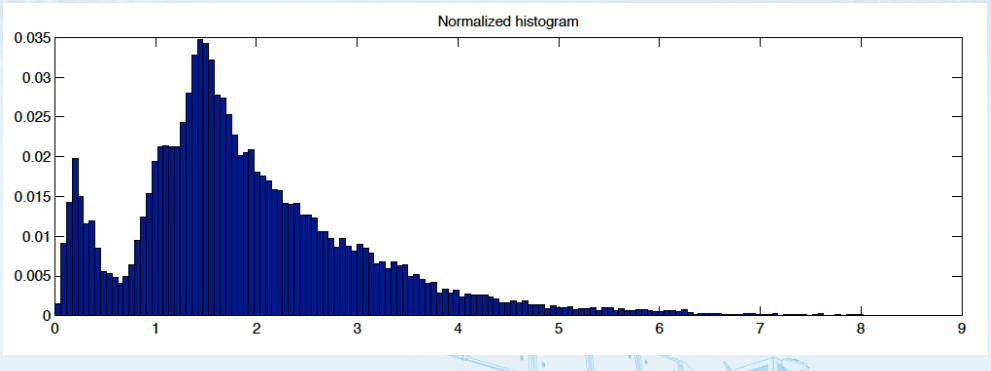


Refrozen lead

Nilas

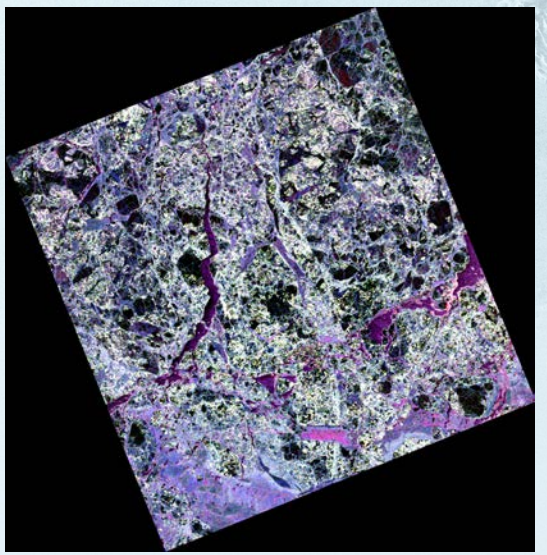
Nilas with frost flower

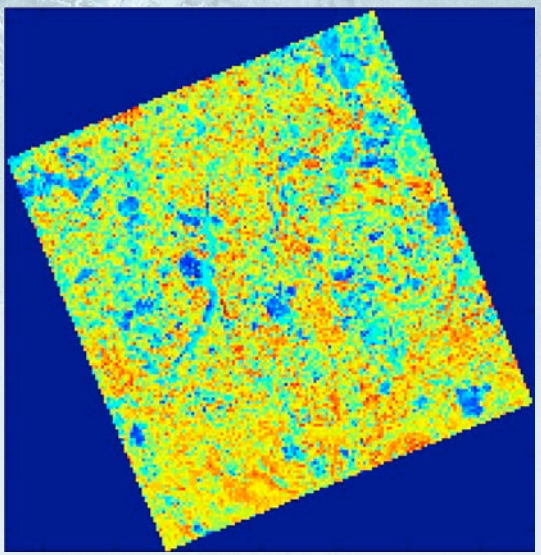
Thin smooth ice

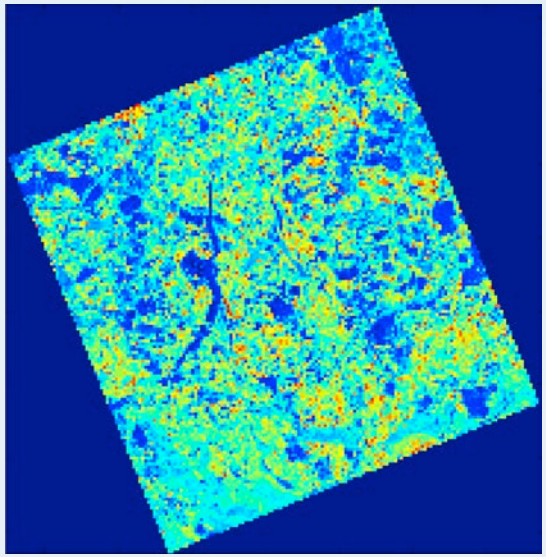


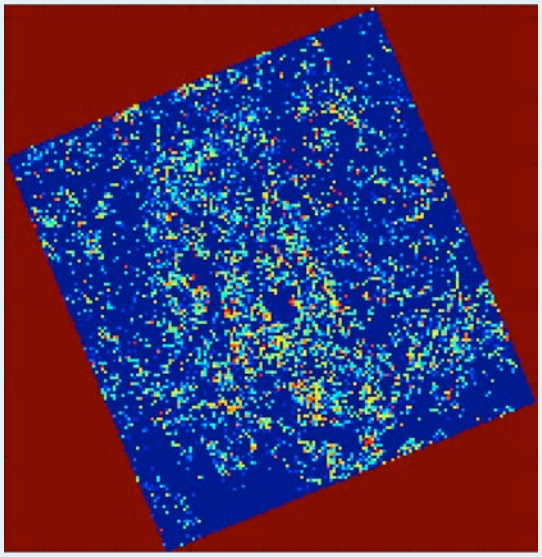
Thickness histogram from EM bird

Shannon Entropy







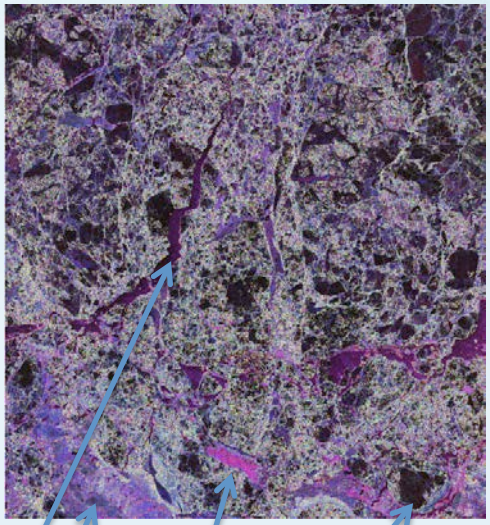


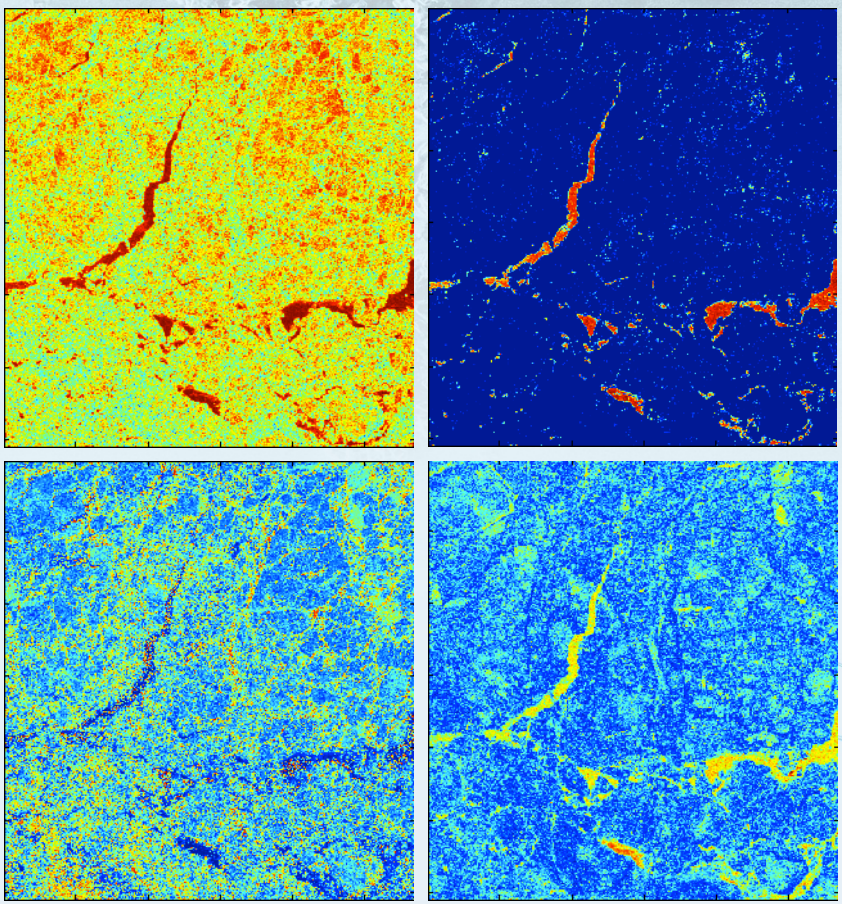
RS2 image: Drift ice North of Svalbard, April2011

Pauli image	Intensity disorder
Polarization disorder	Negentropy

Some polarimetric features

RS2 image: Drift ice North of Svalbard, April 2011

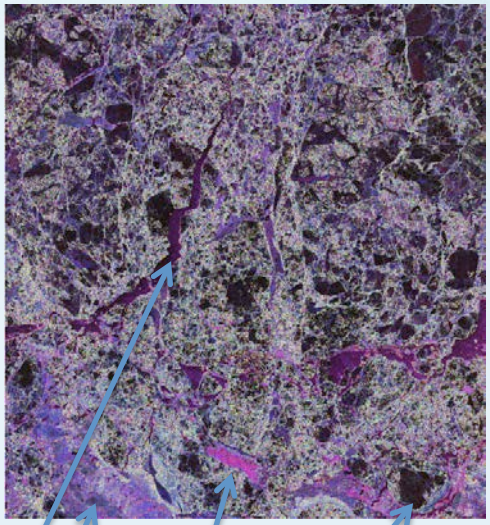


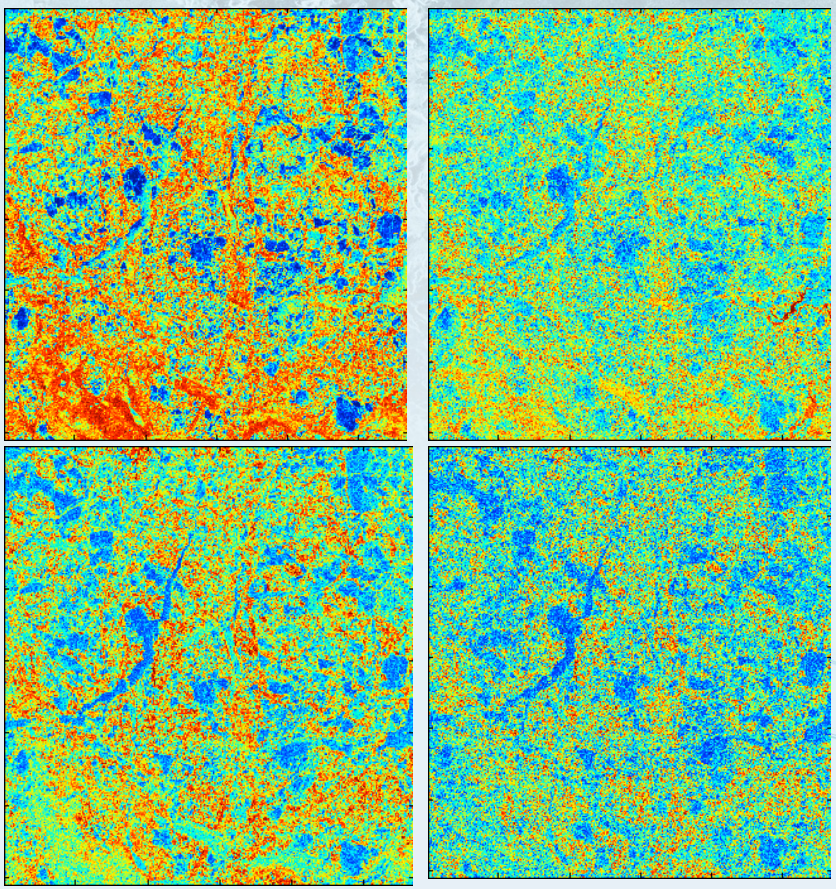


Coh_{sd}	Thresholded Coh_{sd}
Phase Coh_{sd}	Coh_{lr}

Yamaguchi decomposition

RS2 image: Drift ice North of Svalbard, April 2011





surface	Double
Volume	Helix

Intended work flow

Image segmentation from statistical modelling

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Scattering properties from polSAR analysis

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Classification into sea ice types

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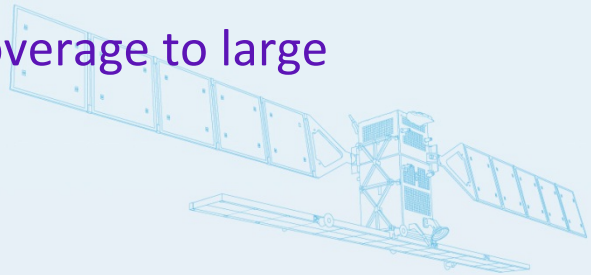
Estimation of geophysical parameters

Some issues:

- Co-location of satellite data and on-the-ice measurements
- Identification the relevant polarimetric features
- Relate polSAR properties to geophysical properties
- From quad-pol observations to dual-pol scenes
- From small coverage to large coverage



Summary

- We have acquired polSAR and in-situ data of Arctic sea ice that allow for detailed studies
- We have developed segmentation tools that combine statistical - and polarimetric signal features. This allow for regional analysis
- The preliminary analysis indicate potential of SAR polarimetry to increase sea ice information retrieval